IMPROVING ABSOLUTE DISTANCE ESTIMATION IN CLEAR AND IN TURBID WATER

by

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SUMMARY PAGE

PROBLEM

To test a training procedure designed to improve the accuracy of distance estimation in both clear and turbid water.

FINDINGS

Performance was initially poorer in one body of water after training in the other body of water. But after training in both clear and turbid water, judgment accuracy improved in both bodies of water.

APPLICATION

The training procedure tested in this experiment would be useful for all diving tasks in which the estimation of object distances is important.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Research Work Unit M4306.03-2050DXC5 - Evaluation of Sensory Aids and Training Procedures on Navy Divers' Visual Efficiency. The present report is No. 9 on that work unit. It was approved for publication on 25 May 1972 and designated as Naval Submarine Medical Research Laboratory Report No. 710.

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ABSTRACT

Since the errors made in estimating distance under water are dependent on the degree of water turbidity, improvement through training in one body of water will not transfer to another body of water if there is a large difference in turbidity. This experiment demonstrated that the transfer problem can be overcome by training divers under different turbidity conditions so that they learn to tailor their corrections to the prevailing conditions. This training procedure would be useful for all diving tasks in which the estimation of object distances is important.

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INTRODUCTION

A diver is usually inaccurate when he estimates the distance of an underwater object.[1-5] The nature of the error made is dependent on two factors, optical distortion and the turbidity of the water.[3,5] The distortion caused by the refraction of light at the water-air interface of the facemask causes objects to appear closer than they really are. However, water turbidity produces a loss of object brightness and contrast, causing an increase in apparent distance which becomes more marked as the physical distance is increased. The net result is that relative to estimates in air, distance is underestimated in clear water, but beyond a relatively near distance, distance is overestimated in turbid water. Mathematically, the relation between perceived and physical distance under water may be expressed as a power function having an exponent which is directly related to the degree of turbidity.[5] The exponent for very clear water is slightly greater than 1.0, and the value increases with increased turbidity, exceeding 1.3 for very turbid water.

Any attempt to improve the accuracy of distance estimation through training is complicated by the critical influence of turbidity. If a diver is informed of the correct distance of an object after each of a series of judgments, he quickly learns to compensate for his errors.[5] However, since different types of errors may occur in waters which differ in turbidity, training in one body of water may cause poorer performance in another body of water. A possible solution to this problem would be to train divers in several bodies of water so that they can learn to tailor their corrections to the degree of turbidity encountered. This possibility was examined in the present experiment.

METHOD

Subjects

Twenty-four Navy enlisted men served as subjects. Most of the subjects had little or no previous diving experience. None had any prior experience with the experimental situation.

Apparatus

Distance estimates in clear water were obtained in a circular, aboveground swimming pool which was 20 ft. in diameter and 44 in. deep. The visibility of the target through the water was at least 20 ft. Since there was 90 percent per meter light transmission through the water (as measured with an alpha meter), the actual visibility may have exceeded 100 ft. Estimates in turbid water were obtained in a small artificial lake. Judgments at the lake were made in water which was equal in depth to that of the pool. The visibility of the target through the water was between 5 and 7 ft.

A similar apparatus was used at each body of water. A rope marked at 6 in. intervals was hung above the surface, between opposite sides of the pool, and between two poles mounted at the lake. Two subjects at a time, wearing face-masks, snorkels, weight belts and rubber wet suits, sat or knelt beneath the surface, below one end of the rope. The rope was not visible to the submerged observer. A partitition mounted between the two subjects prevented them from seeing each other. A horizontal rod, mounted just below the surface and perpendicular to the rope, served as a marker for proper head position. The target was a metal cylinder, 2-3/4 in. in diameter and 4-3/4 in. high (actually an ordinary soft-drink can) which was painted fluorescent red-orange. The target was hung from the rope, at eye level, at various distances from the observer.

Procedure

The subjects were tested in pairs. Each pair was tested (T_1) trained (Tr) and retested (T_2) in each body of water, followed by a final test (T_3) in each body of water. There were four testing orders which differed in regard to where the subjects first received T_1-Tr-T_2, and in which water they first were given T_3. The four orders were as follows:

1. Clear (T_1-Tr-T_2); Turbid (T_1-Tr-T_2); Clear (T_3); Turbid (T_3).

2. Turbid (T_1-Tr-T_2); Clear (T_1-Tr-T_2); Turbid (T_3); Clear (T_3).

3. Clear (T_1-Tr-T_2); Turbid (T_1-Tr-T_2); Turbid (T_3); Clear (T_3).

4. Turbid (T_1-Tr-T_2); Clear (T_1-Tr-T_2); Clear (T_3); Turbid (T_3).

There were six subjects (three pairs) assigned to each testing order. Thus, for 12 subjects the testing began in clear water (orders 1 and 3), and for 12 subjects the testing began in turbid water (orders 2 and 4). Similarly, the testing concluded in clear water for 12 subjects (orders 2 and 3), and concluded in turbid water for 12 subjects (orders 1 and 4).

The subjects were instructed to estimate the distance of the target to the nearest ft. or 1/2-ft. For each test, the target was presented twice at 2, 3, 5, 7, and 10 ft. The subjects, who remained submerged during the entire testing period, signalled each judgment by raising an appropriate number of fingers above the surface. Between judgments, the subjects' view of the target was blocked. For the training sessions, the target was presented 20 times at various distances between 1 and 11 ft., including 1/2-ft. values. The subjects were verbally informed of the correct distance after each judgment.

In the data analysis, the two judgments of each subject at each distance were averaged. Since 75 percent of the judgments at 7 ft. were not obtained in turbid water (due to poor visibility), the missing data was obtained by graphical extrapolation of each subject's raw data. The data for 10 ft. in clear water was omitted from the statistical analysis because no judgments were obtained at

10 ft. in turbid water. An analysis of variance for four factors (testing order, turbidity, test, and distance) with repeated measures on three factors (all but testing order) was performed on the data. Exponents for power functions relating perceived to physical distance were obtained by converting appropriate group medians to log units and obtaining the slope of the best-fitting straight line by the method of least squares.

RESULTS

The results are shown in Figs. 1 and 2, and the analysis of variance is summarized in Table I. Inspection of the data indicated that testing order only affected the results for T_1, a fact confirmed by the statistical analysis. Thus in Fig. 1, the T_1 results for the various Order groups were partially combined. The data for the 12 subjects who were tested first in clear water were combined (orders 1 and 3), as were the data for the 12 subjects who were tested first in turbid water (orders 2 and 4). The differences between the "before" and "after" curves of Fig. 1 represent the effect of prior training in one body of water on the initial estimates in the other body of water. It is apparent that estimates were less accurate after training in water of different turbidity than when there was no training at all. This effect, which is consistent with previous results, was most marked in turbid water.

Since testing order did not have an important effect on the T_2 and T_3 results, the T_2 and T_3 medians for all 24 subjects are compared with the T_1 results in Fig. 2. The T_1 medians of Fig. 2 are for all 24 subjects and thus represent an averaging of the order effects shown in Fig. 1.

Comparison of the Clear and Turbid curves of Figs. 1 and 2 indicates that turbid water produced larger distance estimates than clear water, an effect which increased with distance. Comparison of the "before" curves of Fig. 1 indicates that considerable underestimation occurred in clear water, but underestimation only occurred at the near distances in turbid water. The fact that the median at 7 ft. in turbid water did not actually exceed the physical distance may be due to the extrapolation procedure used to obtain missing data.

As can be seen in Fig. 2, training tended to have opposite effects in the two bodies of water. Since underestimation occurred in clear water and overestimation in turbid water, training resulted in larger estimates in clear water and smaller estimates in turbid water. As a result, performance improved in both bodies of water, and the turbidity differences were reduced. Also, the effect of training increased with distance, and the main difference between tests occurred between T_1 and T_2, with a slight loss of the training effect between T_2 and T_3.

The power-function exponents for T_1 (before), T_2 and T_3, in clear and in turbid water are listed in Table II. The coefficients of determination (r^2) are also listed to indicate how well the data fit power functions. The initial exponent was higher for turbid than for clear water, and the exponents dropped

Table I. Analysis of Variance

Source	DF	MS	F
Between Ss	23	3.13	
A (Testing Order)	3	0.91	0.26
Ss WG	20	3.46	
Within Ss	552	4.50	
B (Turbidity)	1	84.41	39.51***
AB	3	2.30	1.07
B x Ss WG	20	2.14	
C (Test)	2	4.42	2.91+
AC	6	2.84	1.87
C x Ss WG	40	1.52	
D (Distance)	3	639.48	970.09***
AD	9	0.88	1.33
D x Ss WG	60	0.66	
BC	2	22.22	20.33***
ABC	6	3.35	3.06*
BC x Ss WG	40	1.09	
BD	3	16.28	51.47***
ABD	9	0.93	2.95**
BD x Ss WG	60	0.32	
CD	6	1.00	6.52**
ACD	18	0.24	0.79
CD x Ss WG	120	0.31	
BCD	6	2.76	8.54**
ABCD	18	0.16	0.50
BCD x Ss WG	120	0.32	

+ $p < .10$
* $p < .05$
** $p < .01$
*** $p < .001$

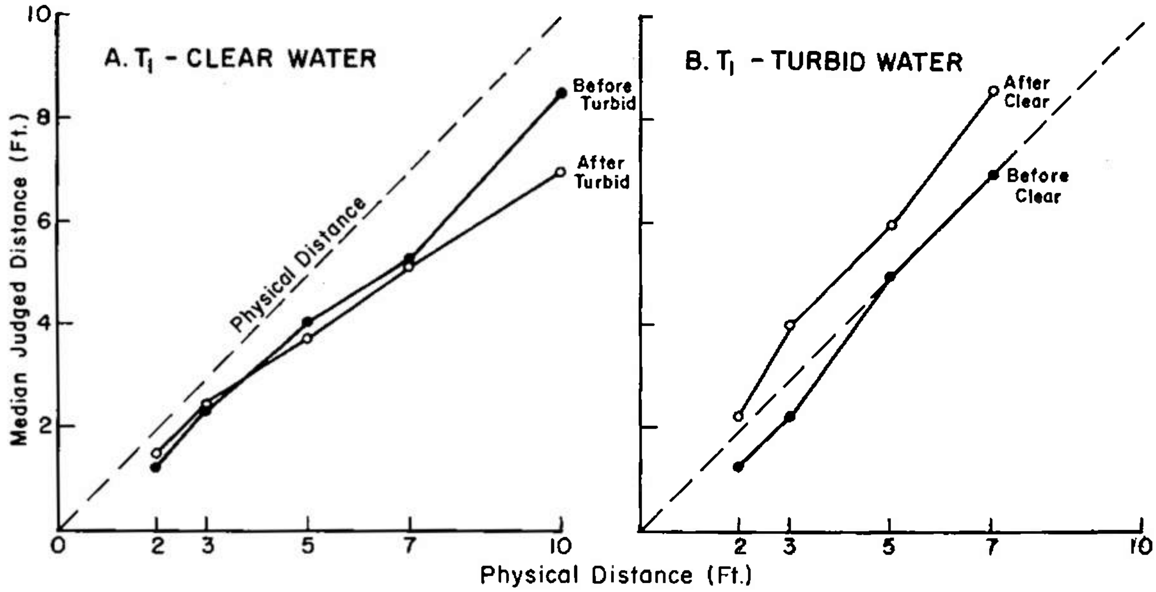

Fig. 1. Median initial judgments (T_1) in clear (A) and in turbid (B) water, both before and after training in the other body of water. The two curves for each body of water are based on separate groups of 12 observers.

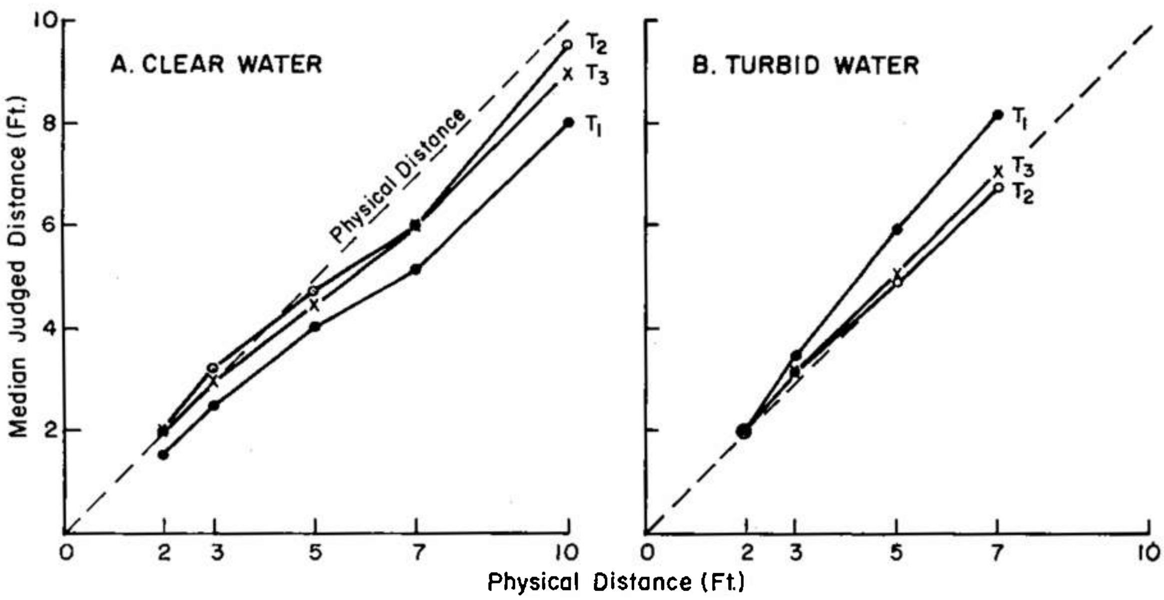

Fig. 2. Effectiveness of training in clear (A) and in turbid (B) water. The medians are based on the estimates of all 24 observers.

Table II. Power-function Exponents

Test	Clear Water Exponent	r^2	Turbid Water Exponent	r^2
T_1[a]	1.14	.990	1.40	.994
T_2	0.91	.988	0.97	.994
T_3	0.91	.996	0.99	.996

[a] Before training in the other body of water

below 1.0 after training. Both of these results are consistent with previous findings.[5]

DISCUSSION

This experiment has verified the detrimental effect of turbidity differences on the ability of training in one body of water to transfer to another body of water. As illustrated in Fig. 1, performance in one body of water, after training in the other body of water, was actually worse than if there had been no training at all. However, the experiment has also shown that training subjects in both turbid and clear water improves performance in both bodies of water. Thus the subjects learned to use different corrections in each body of water to compensate for their errors. This result means that by using a training procedure similar to the one used in this experiment, divers can be trained to estimate distances accurately under a variety of water conditions.

REFERENCES

1. Luria, S. M., Kinney, J. A. S., and Weissman, S. Estimates of size and distance underwater. Am. J. Psychol. 80, 282-286, 1967. (NSMRL Report No. 462, 10 Dec 1965).

2. Ross, H. E. Water, fog and the size-distance invariance hypothesis. Brit. J. Psychol., 58, 301-313, 1967.

3. Kinney, J. A. S., Luria, S. M. and Weitzman, D. O. Effect of turbidity on judgments of distance underwater. Perceptual Motor Skills, 28, 331-333, 1969. (NSMRL Report No. 541, 16 July 1968.)

4. Woodley, J. D., and Ross, H. E. Distance estimates of familiar objects underwater. Underwater Assoc. Reports, 4, 58-61, 1969.

5. Ferris, S. H. Absolute distance perception under water and improvement through training. Naval Submarine Medical Center, Groton, Conn., NSMRL Report No. 670, 28 June 1971.

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